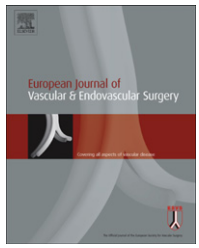
Eur J Vasc Endovasc Surg (2010) **40**, 715–721



Hybrid Repair of the Aortic Arch in Patients with Extensive Aortic Disease

G.A. Antoniou [a], M. Mireskandari [a], C.D. Bicknell [a], N.J.W. Cheshire [a], R.G. Gibbs [a], M. Hamady [b], J.H.N. Wolfe [a], M.P. Jenkins [a,*]

[a] *Regional Vascular Unit, St. Mary's Hospital, Imperial College Healthcare NHS Trust, London, UK*
[b] *Department of Interventional Radiology, St Mary's Hospital, Imperial College Healthcare NHS Trust, London, UK*

Submitted 6 July 2010; accepted 29 August 2010
Available online 2 October 2010

KEYWORDS
Aortic arch;
Endovascular;
Hybrid treatment;
Debranching;
Aortic aneurysm

Abstract *Objective:* To evaluate the outcome of hybrid treatment of the aortic arch with supra-aortic debranching and endovascular stent-graft repair in a selected group of patients with complex disease.
Design: Case series study with retrospective analysis of prospectively collected non-randomised data.
Methods: Patients with hybrid repair of complex arch disease at a single centre over a 6-year period were enrolled in the study. Only patients with extensive arch pathologies requiring debranching of at least the left carotid artery were considered. Patients were divided into those who underwent complete and partial supra-aortic revascularisation. The χ^2 test was used to evaluate differences in outcomes. Logistic regression analyses were applied to identify predictors of poor outcome.
Results: A total of 33 patients were included in the study. Complete and partial arch repair was performed in nine and 24 patients, respectively. The aortic disease extended to the thoracic and abdominal aorta in 39% and 52% of the patients, respectively. One-third of the patients (30%) were treated on an urgent/emergency basis. Elective 30-day mortality and morbidity rates were 13% and 35%, respectively. Early mortality was significantly higher in the complete arch repair group ($p = 0.046$). Pre-existing renal impairment was identified as a poor prognostic factor. All extra-anatomic bypasses remained patent and no aortic disease-related deaths occurred during a mean follow-up period of 23 months (range, 1.5–58 months). Complete arch repair was associated with an increased incidence of late endoleak ($p = 0.018$).
Conclusions: Hybrid treatment of the aortic arch provides a feasible alternative treatment in patients who are high risk for conventional open surgical repair. Careful selection of patients is required to achieve satisfactory results.

* Corresponding author. M.P. Jenkins, BSc, MS, FRCS, FEBVS, Consultant Vascular Surgeon, Chief of Service – Surgery, Cardiovascular and Renal Sciences, Imperial College Healthcare NHS Trust, St Mary's Hospital, Praed Street, London W2 1NY, UK. Tel.: +44 203312 3726; fax: +44 203312 2216.
E-mail address: Michael.Jenkins@imperial.nhs.uk (M.P. Jenkins).

1078-5884/$36
doi:10.1016/j.ejvs.2010.08.024

The conventional treatment of the aortic arch consists of open surgical repair with cardiopulmonary bypass and deep hypothermic circulatory arrest. However, conventional open repair is associated with substantial morbidity and mortality, despite improvements and refinement of these procedures and significant advances in perioperative care.[1–4] Endovascular stent-graft technology has provided vascular and cardiovascular interventionalists with a less invasive therapeutic method of treating thoracic aortic disease. However, the aortic arch presents specific challenges to this treatment, which mainly relate to the angulated morphology and the involvement of the supra-aortic branches. Fenestrated and branched stent-graft technology is at the early stage of development; therefore, hybrid repair with extra-anatomical revascularisation of the arch vessels and subsequent stent grafting of the aorta is a pragmatic alternative for selected patients.[5]

There are limited studies reporting encouraging results with this innovative treatment, but they are restricted by the small numbers of patients and relatively short follow up.[6–13] The purpose of the present study was to present our initial experience, and provide an analysis and evaluation of short- and medium-term results in a larger group of patients.

Methods

Study design

An analysis of all patients with complex aortic arch disease, who underwent hybrid open surgical supra-aortic debranching and endovascular stent-graft repair, was undertaken. This is a retrospective analysis of data prospectively collected on departmental computerised databases. All procedures were performed at St. Mary's Hospital, Imperial College Healthcare NHS Trust, London, between August 2003 and December 2009. The operative and endovascular procedures were performed either together or staged, and all patients provided informed consent for both parts of the treatment.

Patient selection and data collection

Our institution is a referral centre for complex thoraco-abdominal aortic disease, and patients considered high risk for conventional open repair of the aortic arch are referred for a vascular opinion and potential management. The study cohort involved patients, who were referred for treatment of complex aortic arch pathologies. Urgent or emergency cases were also included in the study. Indications for treatment included thoracic/thoraco-abdominal aortic aneurysm, dissection, pseudo-aneurysm and transection of the aorta. Only patients with a reasonable size of aneurysm ($>$6 cm) were considered for hybrid treatment. Operative treatment of the aortic pathology was declined to patients with significant co-morbidities, who were considered high risk for any intervention, and to those with a limited life expectancy. All patients considered for treatment were discussed in our multidisciplinary forum. Hybrid treatment was selected for those patients who were deemed unsuitable for conventional endovascular thoracic stent-graft repair due to extensive aneurysmal involvement of the arch and an inadequate proximal landing zone. A length of at least 15 mm along the lesser curvature of the aortic arch and a maximum diameter of the proximal aortic neck of 38 mm were regarded as safe anatomical criteria for stent grafting alone without supra-aortic debranching. Pre-procedure planning was conducted using computed tomographic (CT) angiograms of the thoracic/abdominal aorta and iliac arteries. Routine preoperative work-up included lung function tests, dynamic cardiac assessment with stress echocardiography and carotid/subclavian duplex ultrasound scanning. Specifically, the vertebral arteries were assessed in all patients with both CT angiography and duplex ultrasonography, and dominance was determined by experienced radiologists and vascular technologists. Demographic, imaging and clinical data extracted from prospectively collected computer-based databases, hospital charts and operative and outpatient records were entered into a purpose-designed database for analysis. Details regarding the causes of death on follow up were extracted from death certificates and general practitioner (GP) records.

Surgical techniques

Single- or two-stage repair was decided on an individual basis, taking into account patient age, co-morbid conditions and aneurysm size and risk of rupture. All hybrid procedures performed in one stage took place in the surgical operating theatre, equipped with a portable digital angiographic system using a C-arm. In cases requiring staged endovascular stent grafting, the second endovascular part of the aortic arch repair was performed in an angiography suite appropriate for open surgical procedures. All procedures were performed under general anaesthesia. Cerebral neuromonitoring with cerebral oxymetry was used in all cases, whereas intra-operative trans-oesophageal echocardiography to monitor cardiac function was selectively used in patients with severe cardiac disease to optimise fluid management. Spinal drain was routinely used in cases where the whole thoracic aorta was covered or in patients, who had their thoraco-abdominal/abdominal aorta previously repaired.

The first part of the hybrid procedures consisted of surgical debranching of the aortic arch, to achieve an adequate proximal landing zone for successful stent-graft placement and sealing. Classification of the thoracic aortic landing zones determined the type of supra-aortic debranching.[14,15] In patients with a proximal landing zone 0, a complete supra-aortic revascularisation with a bifurcated graft from the ascending aorta to the innominate and left carotid artery was performed. Partial arch repair or hemi-arch transposition was undertaken when the aortic pathology extended to zone 1, in which cases an extra-anatomic right-to-left carotid bypass was performed. Revascularisation of the left subclavian artery, in addition to debranching of the innominate and left carotid artery, was selectively performed, taking into account clinical, haemodynamic and imaging data. Specific indications for revascularising the left subclavian artery included previous coronary artery bypass grafting with patent left internal mammary artery, right vertebral artery occlusion, diseased vertebro-

basilar system, previous thoraco-abdominal aortic surgery and repair of the thoraco-abdominal/abdominal aorta as a concomitant procedure to arch hybrid repair. The second part of the procedure consisted of stent-graft deployment to exclude aortic pathology. The transfemoral approach for endovascular access was used in all but one case, where stent-graft access was through sternotomy and ascending aortic Dacron graft. Several commercially available stent-graft systems were employed. Balloon dilatation was selectively performed when a residual endoleak was noticed.

Definitions and outcome endpoints

Outcome criteria and definitions, including technical success, significant inpatient morbidity and death, were based on recommended reporting standards for endovascular aortic aneurysm repair, published by the Ad Hoc Committee for Standardized Reporting Practices in Vascular surgery.[16] Paraplegia or paraparesis observed immediately or upon awakening was defined as immediate neurologic deficits. Those occurring after a period of normal neurologic function were classified as delayed deficits. Technical success, operative (30-day) mortality and morbidity were defined as primary outcome endpoints, whereas secondary outcome measures included late-onset endoleak, late (after 30 days) morbidity and mortality. All patients underwent contrast-enhanced CT scan before discharge, and entered a follow-up surveillance protocol that consisted of a CT scan and review in the vascular outpatient clinic at 6-monthly intervals in the first year and yearly thereafter.

Statistical analysis

Statistical analysis was performed with a computer-based statistical software package (Statistical Package for Social Sciences (SPSS®) 15 for Windows®, SPSS Inc., Chicago, IL, USA). Differences between the groups were tested for statistical significance using the independent *t*-test for continuous variables, and the χ^2 test or Fisher's exact test for categorical variables as appropriate. Furthermore, potential factors associated with poor perioperative outcome were assessed, and a univariate model was fit for each covariate. Exploratory data analyses checked the distribution of values, and significant predictors at level $p < 0.05$ were identified. Forward logistic regression analysis was then applied to adjust for confounding variables and identify significant independent predictors of outcome. All statistical tests were two-tailed, and statistical significance was assumed at $p < 0.05$.

Results

Patients and procedures

Over a 6-year period, 33 consecutive patients underwent hybrid treatment of the aortic arch. Of these, nine patients had a total arch rerouting with a bifurcated graft from the ascending aorta to the innominate and left common carotid artery, and 24 patients underwent a partial arch repair with an extra-anatomic carotid–carotid crossover bypass. The demographic characteristics of the study groups are outlined in Table 1. 23 patients (70%) were referred for an elective repair of the arch pathology, whereas five patients (15%) presented urgently with symptomatic disease, and another five patients (15%) presented as an emergency, with haemodynamic instability or end-organ ischaemia, treated within 24 h of presentation. The aortic arch pathology was an atherosclerotic aneurysm or aneurysmal dilatation of a dissection in 26 cases (79%), aortic dissection in four cases (12%) and pseudo-aneurysm in two cases (6%), and an acute transection of the aorta was treated as an emergency with hybrid repair in another case (3%). The mean aortic diameter in patients treated for an aneurysm was 7.2 cm (range, 6–10.5 cm). All cases of aortic dissection were either urgent or emergency cases, presenting with end-organ ischaemia and treated with hybrid repair of the aortic arch. The pseudo-aneurysm resulted from previous coarctation repair in one patient, and was post-traumatic in another 75-year-old male patient, who was treated on an emergency basis. The arch pathology was localised in the aortic arch in three cases (9%), involved the arch and the whole thoracic aorta in 13 patients (39%) and extended down to the abdominal aorta in the remaining cases (17 patients, 52%). A previous history of aortic surgery was present in 14 patients (42%), and consisted of open or endovascular abdominal aortic aneurysm repair, hybrid or conventional open treatment of thoraco-abdominal aortic aneurysm, endovascular repair of descending aortic pathologies and open repair of the ascending aorta and proximal aortic arch. One patient had a history of an open repair of coarctation of the aorta in childhood and subsequently developed a para-anastomotic pseudo-aneurysm, which was treated with hybrid repair. Two patients (6%) underwent concomitant aortic procedures performed in the same setting of the arch hybrid repair; these procedures were endovascular abdominal aortic aneurysm repair in one case and a hybrid repair of a thoraco-abdominal aneurysm in another case. The Valiant device was used in majority of cases (21 patients), whereas the Gore TAG and the Talent device were used in seven and five cases, respectively. Stent grafts extended to at least the descending thoracic aorta (distal landing zone 4) in all patients. In three patients, the distal landing zone was at the mid-thoracic level (distal landing zone 4, thoracic segments T6–T8), whereas the rest of the patients had their entire thoracic aorta stented (distal landing zone 4, thoracic segments T11–T12). Two patients, who had a visceral hybrid repair (as a simultaneous or previous procedure), had their entire thoracic and abdominal aorta covered with stent grafts (Table 2). No statistically significant differences in the demographic, clinical and pathology characteristics between the two groups were identified (Table 1). However, the complete arch group had an increased incidence of a concomitant aortic procedure compared with the partial arch repair group ($p = 0.017$).

Perioperative outcome

Stenting was possible and completed in all patients selected. Complete technical success was achieved in 27 out of the 33

Table 1 Demographic and clinical characteristics of the study groups.

Type of supra-aortic debranching	Total hybrid procedures $n = 33$ (%)	Complete arch r epair $n = 9$ (%)	Partial arch repair $n = 24$ (%)	p
Mean age (years)	63 (range, 31–87)	66 (range, 53–77)	62 (range, 31–87)	ns
Male/female	26 (79%)/7 (21%)	6 (67%)/3 (33%)	20 (83%)/4 (17%)	ns
HTN	28 (85%)	7 (78%)	22 (92%)	ns
DM	2 (6%)	0 (0%)	2 (8%)	ns
CAD	7 (21%)	1 (11%)	6 (25%)	ns
Dislipidaemia	14 (42%)	3 (33%)	11 (46%)	ns
Smoking	14 (42%)	5 (56%)	9 (38%)	ns
COPD	6 (18%)	1 (11%)	6 (25%)	ns
Renal impairment	6 (18%)	0 (0%)	6 (25%)	ns
Previous aortic procedure	14 (42%)	2 (22%)	12 (50%)	ns
Pathology				
Aneurysm	26 (79%)	9 (100%)	17 (71%)	ns
Dissection	4 (12%)	0 (0%)	4 (17%)	
Other	3 (9%)	0 (0%)	3 (13%)	
Mode of admission				
Elective	23 (70%)	7 (78%)	16 (67%)	ns
Urgent	5 (15%)	1 (11%)	4 (17%)	
Emergency	5 (15%)	1 (11%)	4 (17%)	
Disease extent				
Focal	3 (9%)	0 (0%)	3 (13%)	ns
Thorax	13 (39%)	4 (44%)	12 (50%)	
Thorax & abdomen	17 (52%)	5 (56%)	9 (38%)	
Adjunctive aortic procedure	2 (6%)	2 (22%)	0 (0%)	0.017
Spinal drain	28 (85%)	9 (100%)	19 (79%)	ns
2 stage repair	3 (9%)	1 (11%)	2 (8%)	ns

HTN, hypertension; DM, diabetes mellitus; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; ns, not significant.

patients (82%). The cause of technical failure was an endoleak in all six patients. Endoleak was noticed on completion angiogram and did not resolve with balloon dilatation and/or stent-graft extension. Perioperative complications, occurring within 30 days of intervention, affected 13 patients (39%). The elective and urgent/emergency morbidity rates were 35% and 50%, respectively. The most common complications in order of frequency were renal impairment requiring temporary dialysis (18%), pulmonary complications (12%), stroke (12%), spinal cord ischaemia (6%) and adverse cardiac events (6%). The two patients who developed spinal cord ischaemia had permanent paraplegia without any recovery. Both patients were treated electively and remained cardiovascularly stable during the perioperative period. Spinal cord ischaemia had an immediate presentation. Endoleak occurring either intra-operatively or within 30 days of intervention developed in 14 patients (42%). Of these, three had type Ia endoleak alone, four had both type Ia and type Ib or type II endoleak, three patients had type Ib endoleak and another four patients developed type II endoleak from the left subclavian artery. No differences in the frequency of early-onset (within 30 days) endoleak and overall morbidity rates between the complete and partial arch repair groups were identified. However, complete supra-aortic debranching was associated with an increased incidence of acute renal failure (44% vs. 8%, $p = 0.017$) and spinal cord ischaemia (22% vs. 0%, $p = 0.017$, Table 3). Seven patients died within 30 days (21%). The elective and urgent/emergency mortality rates were 13% and 40%, respectively. Two deaths occurred on table, one due to retrograde aortic dissection during stent-graft insertion and another due to hypovolaemic shock in a case of an

Table 2 Proximal and distal landing zones.

	Proximal landing zone	
Distal landing zone	Zone 0	Zone 1
Proximal thoracic	0	0
Mid-thoracic	0	3
Distal thoracic	8	20
Abdominal	1	1

Table 3 Outcome after hybrid aortic arch repair.

Type of supra-aortic debranching	Total hybrid procedures $n = 33$ (%)	Complete arch repair $n = 9$ (%)	Partial arch repair $n = 24$ (%)	p
Technical failure	6 (18%)	2 (22%)	4 (17%)	ns
Early endoleak	14 (42%)	4 (44%)	10 (42%)	ns
30-day morbidity	13 (39%)	5 (56%)	8 (33%)	ns
Stroke	4 (12%)	1 (11%)	3 (13%)	ns
Paraplegia	2 (6%)	2 (22%)	0 (0%)	0.017
Renal failure	6 (18%)	4 (44%)	2 (8%)	0.017
Cardiac events	2 (6%)	1 (11%)	1 (3%)	ns
Pulmonary events	4 (12%)	2 (22%)	3 (13%)	ns
Overall 30-day mortality	7 (21%)	4 (44%)	3 (13%)	0.046
Elective 30-day mortality	3/23 (13%)	2/7 (29%)	1/16 (6%)	ns
Late morbidity	6/26 (23%)	2/5 (40%)	4/21 (19%)	ns
Late mortality	5/26 (19%)	1/5 (20%)	4/21 (19%)	ns
Late endoleak	9/26 (35%)	4/5 (80%)	5/21 (24%)	0.018

ns, not significant

emergency repair of an aortic transection. The retrograde dissection occurred in a 53-year-old male patient, who was urgently treated for a symptomatic 10 cm aortic aneurysm. A Valiant stent-graft device was deployed after complete supra-aortic debranching, and the dissection was presumed to have resulted from wire manipulation within the aortic arch. Other causes of death included a cerebrovascular event in two patients, myocardial infarction, cardiac arrest and hypoxic brain injury in another two patients and multi-organ failure in one case. Patients, who underwent a complete arch repair, had increased overall 30-day mortality rate compared with those having undergone partial arch repair (44% vs. 13%, $p = 0.046$, Table 3). Differences in elective mortality between the two groups did not reach statistical significance (29% vs. 6%, $p = 0.144$, Table 3).

The relationship between preoperative risk factors and outcome as expressed by 30-day mortality and morbidity was evaluated using univariate logistic regression analysis. All parameters listed in Table 1 were included in the analysis of potential determinants of outcome. The only variables significantly associated with poor outcome were pre-existing renal impairment, defined as serum creatinine greater than 180 μmol l^{-1} (odds ratio (OR) 8.50; 95% confidence interval (CI), 0.87—83.49; $p = 0.039$), and urgent or emergency operation (OR 4.38; 95% CI, 0.88—21.70; $p = 0.062$). Predictive parameters for poor outcome were further assessed using multiple logistic regression analysis by including all factors with a $p < 0.2$ in the univariate analyses in a full model. None of the above variables remained independent predictors for complications or death in the multivariate final model, even though renal impairment had an adjusted p value of 0.066 (Table 4). Five out of the six patients with preoperative renal impairment had a poor perioperative outcome (83%), whereas the corresponding value for those without renal impairment was 37% (10/27 patients, $p = 0.039$).

Outcome on follow-up

The mean follow-up period for the whole study population was 23 months (range, 1.5—58 months). One patient was lost to follow-up. All endografts and supra-aortic bypass grafts remained patent during follow up. Late (up to the end of follow-up) morbidity and mortality occurred in 23% and 19% of patients, respectively. None of the late deaths was associated with the aortic pathology or previous intervention. Morbidity was due to transient cerebrovascular episodes in two patients, cardiac complications in another two patients, and was associated with a ruptured iliac artery in one patient. One patient developed infection of the carotid crossover graft 2 months after the hybrid procedure, and was treated with removal of the prosthetic graft and re-do carotid—carotid crossover using the long saphenous vein as a conduit. Persistent early- and late-onset endoleak detected on surveillance CT scans was noticed in nine patients (35%). Three patients had type Ia endoleak, which was managed expectantly with close surveillance, as no increase in aortic sac diameter on serial CT scans was noticed. Of the three type II endoleaks, two were managed conservatively, and the third was successfully treated with left subclavian artery embolisation. One

Table 4 Predictive factors associated with poor outcome.

Risk factor	Univariate model OR (95% CI)	Univariate model p value	Final model p value
Renal impairment	8.500 (0.865—83.493)	0.039	0.066
Urgent/emergency operation	4.375 (0.882—21.707)	0.062	0.561
Complete arch repair	3.333 (0.664—16.736)	0.134	0.888

type III endoleak required stent-graft realignment, whereas an expectant policy was followed for two type Ib endoleaks. Total aortic arch repair was associated with an increased incidence of endoleak in the follow-up period compared with the partial arch repair group ($p = 0.018$, Table 3).

Discussion

Even though open surgical repair is considered the treatment of choice for aortic arch disease in low-risk patients, such invasive surgery is accompanied by significant in-hospital mortality rates, which, in several large series, exceed 20%.[4,17,18] Furthermore, these procedures are associated with high frequency of transient or permanent neurological and cognitive deficits, whose rates range between 3% and 17%.[1–4] Hybrid repair of the aortic arch with supra-aortic debranching prior to stent-graft deployment provides the advantage of reducing invasiveness by avoiding aortic cross-clamping and circulatory arrest.[14,19] However, there still are difficulties with the application of endovascular techniques in an anatomically challenging area, which are related to arch angulation, high blood flow and substantial pulsatile movement of this portion of the aorta.

The present study describes our experience of a larger series with longer follow-up compared with previously published reports. Only high-risk patients with significant co-morbidities, who were excluded from conventional open surgical repair, were considered for hybrid repair and enrolled in the study. The present cohort includes complex aortic disease, which, in more than half of the patients, extended to the abdominal aorta, and 91% involved treating the arch and the entire descending aorta. Furthermore, even though literature provides a baseline upon which innovative endovascular techniques may be assessed, direct comparisons with open surgical treatment is not feasible, mainly because of the surgical risk discrepancy between the study groups considered for open and hybrid repair. Recently published pooled analysis of the reported outcomes of previous series of hybrid aortic arch repair found a perioperative morbidity and mortality rate of 21% and 9%, respectively.[20] However, most of the series included in this systematic review contained small numbers of patients, increasing the possibility of being affected by publication bias. Furthermore, the aortic pathology and clinical details including the mode of presentation were not reported in many of these studies, which make comparisons of operative outcomes difficult. In addition, no reporting standards for documentation of complications and deaths were used by most of these studies, resulting in conflicting results and lack of uniform reported outcomes.

The present series has also demonstrated a greater incidence of early-onset endoleak. Five of the 15 patients who developed endoleak required further treatment with either stent-graft extension for types Ia and Ib endoleaks or coil embolisation for type II endoleaks from the left subclavian artery. Seven endoleaks were observed during the follow-up period, which underlines the necessity for close surveillance in these patients. Closer surveillance is particularly required for patients undergoing complete arch repair, as, from our analysis, it was found that this group of patients was associated with a significantly increased frequency of late-onset endoleak. The fact that zone 0 repair was associated with increased incidence of late endoleak may reasonably be explained by the fact that the stent graft is placed more proximally in the angulated aortic arch, which is an anatomically challenging area. Despite obtaining a longer landing zone in zone 0 cases, the late endoleaks probably represent lack of conformability. Furthermore, anatomical factors should carefully be considered with high-quality CT angiography before embarking on stent grafting of difficult arch anatomy to achieve higher technical success rates and reduce the incidence of endoleak.

To further analyse the outcomes of hybrid treatment of the aortic arch and obtain homogenous groups with regard to the operative treatment, we divided the study population into complete and partial arch repair groups. The operative and technical characteristics (sternotomy vs. neck incisions, bilateral vs. unilateral carotid revascularisation) are different in the two groups as well as the length of the aortic arch stented; thus, the outcome was separately assessed for complete and partial arch repair. Our analysis found no differences in technical success, early-onset endoleak and 30-day morbidity rates, whereas 30-day mortality was significantly increased in the complete arch repair group. Furthermore, paraplegia and renal failure were more common in patients having undergone complete repair of the aortic arch. These figures may be explained by the increased incidence of adjunctive aortic procedures involving stent grafting of the infrarenal or thoracoabdominal aorta in this group of patients. However, larger numbers of patients are required to allow us to reach definite conclusions regarding the outcomes in the two groups of patients. Similar to previous series, the incidence of stroke remained significant, whereas permanent paraplegia affected two patients, one of whom had previous open infrarenal aortic aneurysm repair. The mechanisms and underlying aetiology of neurological deficits are poorly defined. It seems, however, that embolic events and haemodynamic changes in the cerebral circulation are significant contributors to perioperative cerebrovascular events. Careful preoperative assessment of the extracranial and intracranial circulation as well as intra-operative measures, such as cautious manipulation of central vessels during debranching and endovascular manoeuvres, might reduce the incidence of these formidable complications. The patients who developed lower limb paralysis had a spinal drain inserted, underwent stent grafting of the whole thoracic aorta (distal landing zone 4), and one of them had previously undergone infrarenal aortic aneurysm repair. Mechanisms of spinal cord injury include the length of aortic coverage and peri/postoperative hypotension, as spinal cord perfusion pressure is directly related to systemic blood pressure and inversely proportional to cerebro-spinal fluid pressure.[21] In addition, careful preoperative consideration should be given to previous history of treated aortic disease and the extent of the aorta that has to be treated.

Risk factor analysis found that pre-existing renal impairment, urgent/emergency operation and total arch repair were poor prognostic indicators, with renal impairment being the strongest factor in the univariate model.

Careful selection of patients, taking into consideration clinical and anatomical imaging features, might diminish complication and technical failure rates. Furthermore, newer stent-graft devices with increased arch conformability may be associated with better results in terms of technical success and early and late endoleak rates.

Conclusions

Hybrid treatment of the aortic arch with supra-aortic debranching and endovascular stent-graft repair provides a feasible alternative treatment in patients who are high-risk for conventional open surgical repair. However, perioperative morbidity and mortality rates remain significant. Careful selection of patients and consideration of anatomical features are required to achieve satisfactory results. Newer stent-graft devices with increased conformability may be associated with improved results.

Conflict of Interest

None.

Funding

None.

References

1 Sundt 3rd TM, Orszulak TA, Cook DJ, Schaff HV. Improving results of open arch replacement. *Ann Thorac Surg* 2008;**86**(3):787—96.
2 Strauch JT, Böhme Y, Franke UF, Wittwer T, Madershahian N, Wahlers T. Selective cerebral perfusion via right axillary artery direct cannulation for aortic arch surgery. *Thorac Cardiovasc Surg* 2005;**53**(6):334—40.
3 Nakai M, Shimamoto M, Yamazaki F, Fujita S, Aoyama A, Chin T. Long-term results after surgery for aortic arch nondissection aneurysm. *Kyobu Geka* 2002;**55**(4):280—4.
4 Okita Y, Ando M, Minatoya K, Kitamura S, Takamoto S, Nakajima N. Predictive factors for mortality and cerebral complications in arteriosclerotic aneurysm of the aortic arch. *Ann Thorac Surg* 1999;**67**(1):72—8.
5 Schoder M, Lammer J, Czerny M. Endovascular aortic arch repair: hopes and certainties. *Eur J Vasc Endovasc Surg* 2009;**38**(3):255—61.
6 Canaud L, Hireche K, Berthet JP, Branchereau P, Marty-Ané C, Alric P. Endovascular repair of aortic arch lesions in high-risk patients or after previous aortic surgery: midterm results. *J Thorac Cardiovasc Surg*; 2009;. doi:10.1016/j.jtcvs.2009.09.022.
7 Weigang E, Parker J, Czerny M, Peivandi AA, Dorweiler B, Beyersdorf F. Endovascular aortic arch repair after aortic arch de-branching. *Ann Thorac Surg* 2009;**87**(2):603—7.
8 Chan YC, Cheng SW, Ting AC, Ho P. Supra-aortic hybrid endovascular procedures for complex thoracic aortic disease: single center early to midterm results. *J Vasc Surg* 2008;**48**(3):571—9.
9 Melissano G, Civilini E, Bertoglio L, Calliari F, Setacci F, Calori G. Results of endografting of the aortic arch in different landing zones. *Eur J Vasc Endovasc Surg* 2007;**33**(5):561—6.
10 Czerny M, Gottardi R, Zimpfer D, Schoder M, Grabenwoger M, Lammer J. Mid-term results of supraaortic transpositions for extended endovascular repair of aortic arch pathologies. *Eur J Cardiothorac Surg* 2007;**31**(4):623—7.
11 Bergeron P, Mangialardi N, Costa P, Coulon P, Douillez V, Serreo E. Great vessel management for endovascular exclusion of aortic arch aneurysms and dissections. *Eur J Vasc Endovasc Surg* 2006;**32**(1):38—45.
12 Saleh HM, Inglese L. Combined surgical and endovascular treatment of aortic arch aneurysms. *J Vasc Surg* 2006;**44**(3):460—6.
13 Schumacher H, Von Tengg-Kobligk H, Ostovic M, Henninger V, Ockert S, Böckler D. Hybrid aortic procedures for endoluminal arch replacement in thoracic aneurysms and type B dissections. *J Cardiovasc Surg (Torino)* 2006;**47**(5):509—17.
14 Criado FJ, Barnatan MF, Rizk Y, Clark NS, Wang CF. Technical strategies to expand stent-graft applicability in the aortic arch and proximal descending thoracic aorta. *J Endovasc Ther* 2002;**9**(Suppl. 2). II32-8.
15 Mitchell RS, Ishimaru S, Ehrlich MP, Iwase T, Lauterjung L, Shimono T. First International Summit on Thoracic Aortic Endografting: roundtable on thoracic aortic dissection as an indication for endografting. *J Endovasc Ther* 2002;**9**(Suppl. 2):II98—105.
16 Chaikof EL, Blankensteijn JD, Harris PL, White GH, Zarins CK, Bernhard VM. Ad hoc committee for standardized reporting Practices in vascular surgery of the Society for vascular Surgery/American Association for vascular surgery. Reporting standards for endovascular aortic aneurysm repair. *J Vasc Surg* 2002;**35**(5):1048—60.
17 Moon MC, Morales JP, Greenberg RK. The aortic arch and ascending aorta: are they within the endovascular realm? *Semin Vasc Surg* 2007;**20**(2):97—107.
18 Desai ND, Szeto WY. Complex aortic arch aneurysm and dissections: hybrid techniques for surgical and endovascular therapy. *Curr Opin Cardiol* 2009;**24**(6):521—7.
19 Kpodonu J, Diethrich EB. Hybrid interventions for the treatment of the complex aortic arch. *Perspect Vasc Surg Endovasc Ther* 2007;**19**(2):174—84.
20 Antoniou GA, El Sakka K, Hamady M, Wolfe JHN. Hybrid treatment of complex aortic arch disease with supra-aortic debranching and endovascular stent graft repair. *Eur J Vasc Endovasc Surg* 2010;**39**:683—90.
21 Amabile P, Grisoli D, Giorgi R, Bartoli JM, Piquet P. Incidence and determinants of spinal cord ischaemia in stent-graft repair of the thoracic aorta. *Eur J Vasc Endovasc Surg* 2008;**35**(4):455—61.